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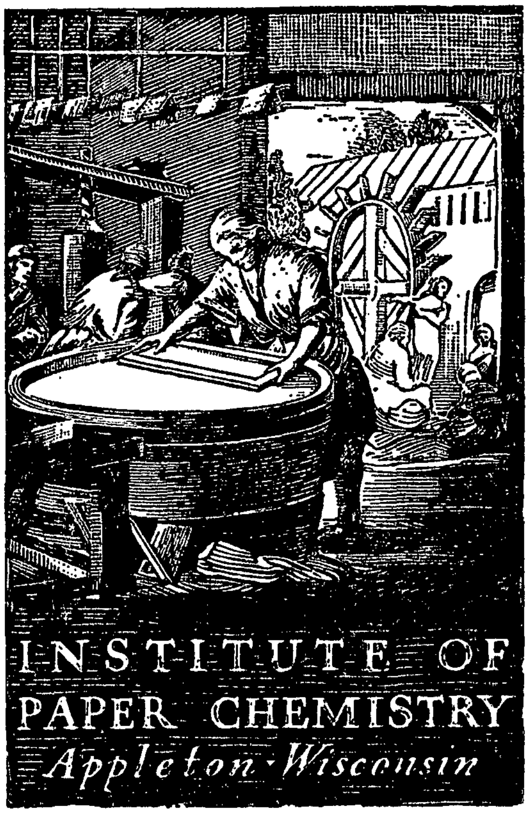

EFFECT OF SHEET PROPERTIES ON SACK FAILURE PATTERNS IN THE PROGRESSIVE HEIGHT FACE DROP TEST

Project 2033

Report Twenty

A Progress Report

to

MULTIWALL SHIPPING SACK PAPER MANUFACTURERS

April 23, 1962

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

The progression of failure in the sack drop test is so rapid that unless high-speed photography is employed, the test observer can only note the appearance of the final failure pattern. While observations of the failure pattern give no indication of the point of initiation of failure it appears reasonable that the progression of the failure line should be governed in part by factors similar to those which initiate failure, i.e., the applied strains and the resistance of the sheet to failure in its two principal directions.

For such reasons, the progressive height face drop failure patterns exhibited by the regular and extensible sacks from the recent fabrication run were analyzed. Failure patterns were segregated into a number of broad categories or types and the frequency of each type failure was determined for each run. The failure pattern types are listed below, together with a short descriptive phrase (sketches, photographs, and more extensive descriptions will be found in the text).

Type	Description
A	Lengthwise failure line on face
B	Forked lengthwise or diagonal failure line on face
C	Failure line around corner
D	Short machine direction failure line at top or bottom
E	Diagonal failure line on side
FS	Top or bottom crease
FX	Side crease
G	Cross direction failure line in face or end
H	Valve or corner

In Types A, B, D, and FS, the failure line seemed predominantly parallel to the machine direction of the sheet--much as if the sack wall was pulled apart by cross-direction stresses. In the analysis, therefore, these types were qualitatively treated as cross-machine type failures.

The results of the analyses are summarized below:

A. Comparison of regular and extensible sack failure patterns.

1. Lengthwise (A-type) failures increased from 13% for the regular to 55% for the extensible sacks.
2. Failures running around a corner decreased from 32% for the regular to 13% for the extensible sacks.
3. The extensible sacks exhibited lower percentage frequencies for the B, E, FX and G type failure patterns.

B. Relationship of failure pattern frequency to sheet properties.

1. The frequency of occurrence of cross-machine failure types (A, B, D, and F) was not obviously related to individual sheet properties such as tensile energy absorption (TEA). However, a reasonably favorable relationship was obtained between cross-machine failure type frequency and the ratio of machine to the sum of machine and cross-machine TEA. Somewhat similar relationships were obtained with the stretch and Frag tests.
2. No relationship appeared to exist between cross-machine failure type frequency and ratios involving Elmendorf tear.

In conclusion, the results indicate that the failure patterns obtained in the progressive height face drop test are a function of the energy absorption characteristics of the sheet in the machine and cross-machine direction.

INTRODUCTION

As a sack impacts the base in a face drop test, the outward movement generates biaxial stresses and strains in the sack walls. Present theoretical treatments appear inadequate to describe the magnitude of the induced strains as a function of location in the sack, material properties, drop height, sack dimensions, commodity density, flatness of drop, etc. Experimental data in this area are also limited (1). However, one qualitative implication is that face drop sack performance will be related to the properties of the sheet in both principal directions.

In general, it would be expected that failure originates in localized areas where the applied stress (strain) on a given drop exceeds the capacity of the sheet to accept such stresses (strains). As bonds and/or fibers break in the affected areas, stress is concentrated in the remaining bonds and fibers and the failure line progresses rapidly into adjacent areas due to the stored up energy in the sheet and contents.

Therefore, it appears that, in qualitative terms, at least four factors govern failure initiation. They are the applied stresses and strains in each direction and the resistance of the material in each direction.

The above remarks consider factors important to failure initiation, but the test observer cannot, in general, locate the point of initiation of failure. In short, it is the final pattern of failure that is seen. In qualitative terms the failure pattern should be influenced by at least four factors. They are:

a. The biaxial strain field existing at the apex of the failure boundary at any instant.

b. The relative resistance to failure of the sack paper in the machine and cross-machine directions and their interaction.

c. The stored energy in the sack walls and contents.

d. The sack dimensions.

The second statement simply notes that the response of an orthotropic material subjected to plane biaxial stresses and strains is a function of its properties in its two principal directions in the plane of the sheet. As developed in later pages, the differences in failure pattern between regular and extensible sacks are attributed mainly to this factor, i.e., the change in ratio of machine and cross-machine properties between regular and extensible papers.

With regard to (a), Nadai (2) in summarizing the behavior of metals under biaxial stresses discussed a series of experiments carried out by E. A. Davis and other investigators with hollow cylindrical specimens simultaneously pulled in tension and subjected to internal pressure. Defining $n=\sigma_t/\sigma_a$ where σ_t and σ_a are the circumferential and axial stresses, respectively, then $n = 0$ corresponds to simple axial tension and $n = \infty$ corresponds to pure circumferential tension. When specimens were tested to failure at various values of n, it was found that the failure line was perpendicular to the axis of the cylinder for n less than about 0.75. As n increased above 0.75, the failure line was parallel to the axis of the cylinder. Thus, in this example, the failure pattern depended on the ratio of the applied stresses. Similar behavior would be expected for an orthotropic material.

The same reference also noted that the amount of stored energy in the pressure fluid had a marked influence on the formation and type of fracture surface. Shear-type fractures changed into cleavage-type fractures in high stored energy tests, although for a given n the direction of the failure line was similar to that obtained in the low energy tests. These remarks are pertinent to sack behavior because of the large stored energy in the contents at impact. In the case of paper it is known that the amount of stored energy affects the fracture surface obtained. For example, if short-span tensile tests are performed at slow rates, failure takes place slowly because the stored energy in the specimen is relatively small and the fractured surface presents a "feathery" appearance. In long-span tensile tests performed at normal test rates failure occurs rapidly because the greater amount of energy stored in the specimens is relatively large and the fractured surface is quite different in appearance from that obtained in the short-span low stored energy test.

The intent of the above remarks is to present information for other materials which may have a bearing on sack behavior. Analogies with other materials cannot be safely pursued too far where differences in basic structure, etc., are involved; however, neither should such experiences be summarily dismissed. With this in mind, it appeared reasonable to expect that sack failure patterns could be grouped into a number of categories and that the frequency of certain types of failure patterns would be related to the directional properties of the sheet.

Finally, it is conjectured that the type of failure pattern obtained will also be a function of the sack dimensions. This hypothesis will be developed in a later report; however, limited trials to date involving rather extreme changes in length-to-width ratio of sack dimensions appear to support the hypothesis.

As part of the record of each sack drop test on this project, the failure pattern is customarily sketched by the test operators for all tests. With the above considerations in mind, the failure patterns for the progressive height face drop tests performed at 50% R.H. on the regular and extensible sacks from the recent fabrication run were analyzed. The following discussion is, therefore, specifically concerned with the appearance and direction of sack failure patterns.

With the above in mind, failure patterns were segregated into a number of broad categories based on the failure sketches and available photographic records. Of necessity, the definitions for the various categories are not precisely drawn and may require modification as dictated by insight and experience. From this standpoint, they represent an <u>initial</u> attempt to classify failure types.

It will be noted that assigning a given failure pattern to a given failure pattern type involves subjective judgment and no two observers would be expected to agree in every case. Thus, the actual failure patterns do not always neatly fit into the various categories. For example, the decision to class a given failure pattern as "A" or "B" type was sometimes different. Similar difficulties were encountered in distinguishing between "C" and "D" type patterns at times and in determining that a crease failure was involved. It is felt, however, that experienced personnel would grade the failure patterns of most sacks in the same manner and reach much the same conclusions regarding failure pattern frequency.

DEFINITION OF FAILURE PATTERN TYPES IN THE PROGRESSIVE HEIGHT FACE DROP TEST

GENERAL

As mentioned previously, a sketch of the failure pattern for each sack tested was made during the course of the testing. A typical sketch is shown in Fig. 1. It may be remarked that the diagrams only crudely indicate the approximate location of the failure line and fine distinctions between failure lines from sack-to-sack were impossible. For this reason, this initial examination was purposely restricted to dividing the failure patterns into a number of broad classes. It should also be mentioned that the failure sketches made no distinction between ply behavior except where it was noted that one or more plies failed prior to the remaining plies. However, it was commonly observed that in most instances the failure patterns for each of the plies were basically similar.

In addition to the above, photographs were taken of a number of sacks from each run after failure. The photographs proved quite helpful in defining types of failure and all sacks being currently evaluated are photographed. Even photographs, however, may not necessarily reveal all the detail desirable depending on the orientation of the camera, failure pattern, etc. In the ideal, careful examination of each individual sack by experienced personnel, coupled with extensive photographic records, would be most helpful.

DEFINITION OF FAILURE TYPES

From examination of the failure sketches and photographs, it appeared that most failure patterns could be subdivided into eight types. Typical sketches of the eight types are shown in Fig. 2. A discussion of each type follows.

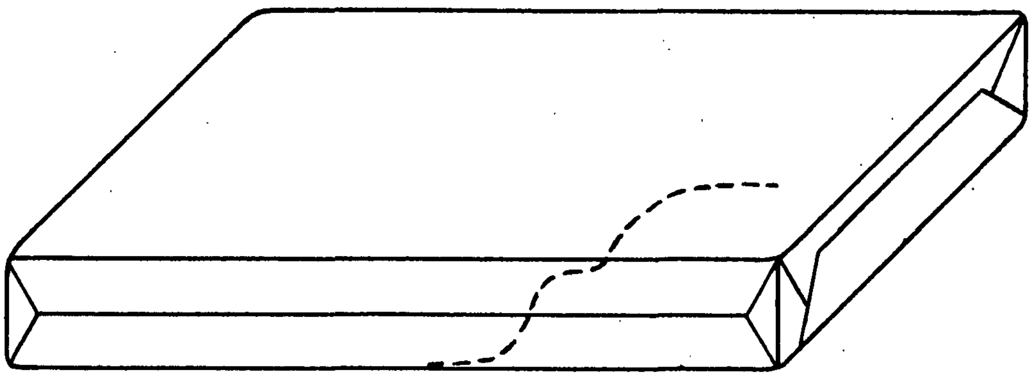

Figure 1. Typical Failure Pattern Diagram

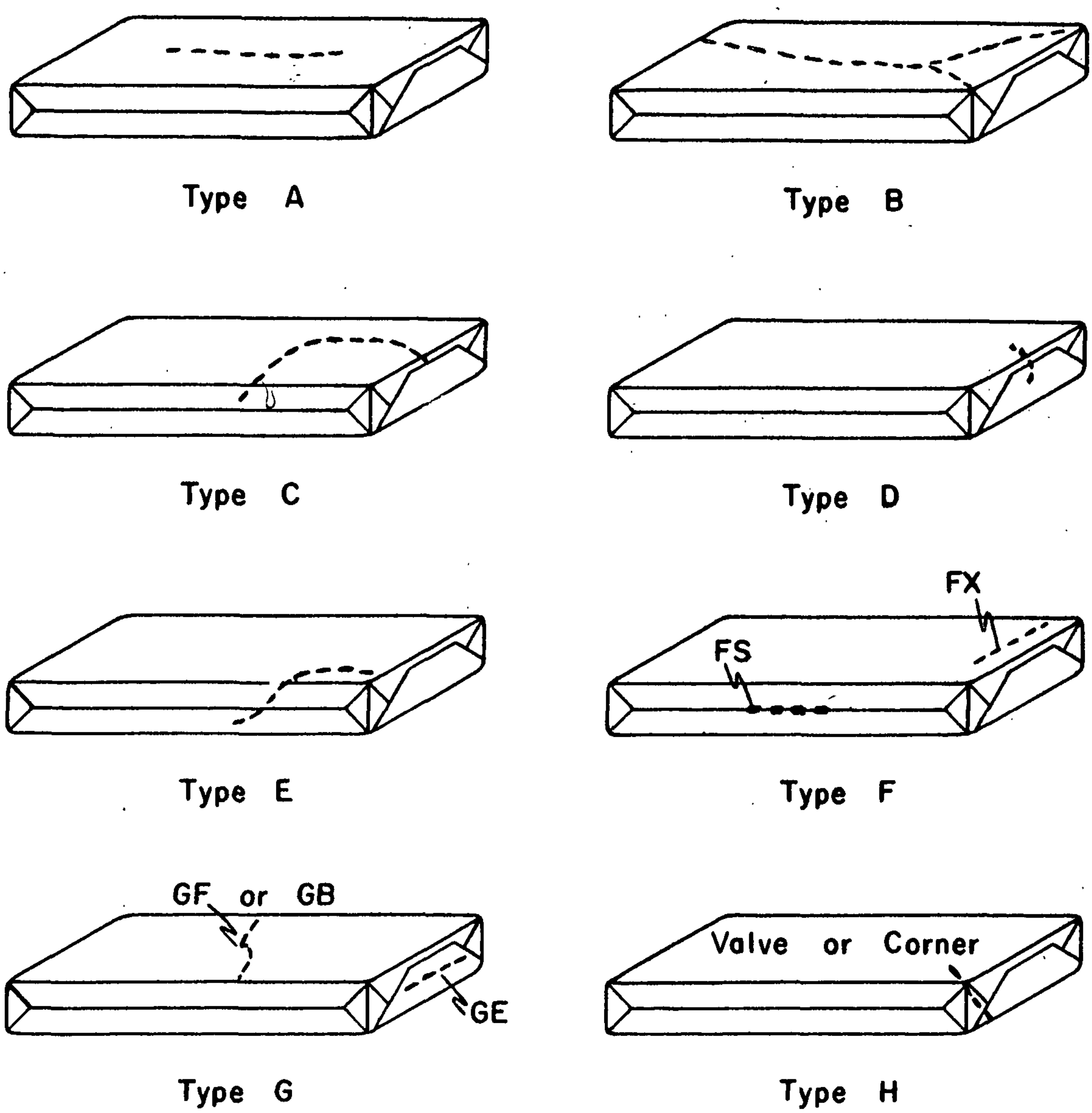

Figure 2. Failure Types

Type A. Lengthwise Type

The characteristic pattern for this type is a lengthwise failure line approximately parallel to the machine direction and extending over a major portion of the length. The ends of the failure line may extend into the top or bottom glued areas and deviations from the predominantly machine direction orientation. may occur at the extreme ends of the failure line. The following subdivisions were noted in analyzing the data

Code

AF -- failure in face panel

AB -- failure in back (glue seam) panel

ABS -- failure in back (glue seam) panel identified as along glue seam in test record.

Photographs of representative failures of this type are shown in Fig. 3. For Runs 17 and 18, the failure line is on the back panel along the edge of the pasted seam. Face panel failures are shown for Runs 16 and 24.

Type B. Diagonal or Forked Lengthwise Tears

In this type, the failure line appears as a lengthwise rupture in the face or back of the sack having a fork at some point in its path or a diagonal tear from corner to corner, as shown in Fig. 4. The branches of the fork often progress to the corners but may deviate into the side of the sack (see Fig. 4). In many instances it is difficult to distinguish between "A" and "B" type patterns and it is quite possible that one is a variant form of the other. Therefore, consolidation of "A" and "B" types into one broad category might be justified. However, in the initial examinations the classes were kept separate and two subdivisions were made.

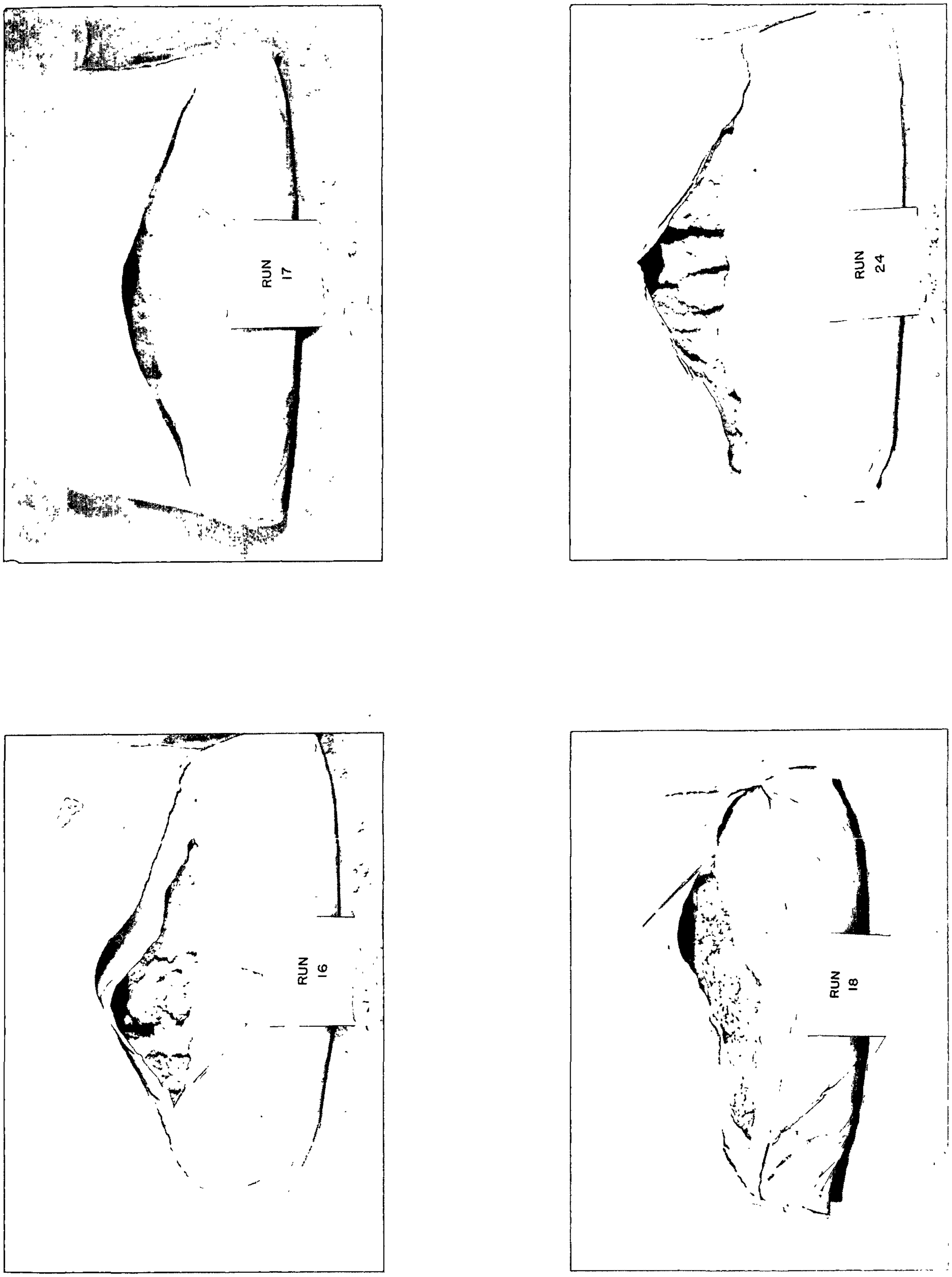

Figure 3. Photographs of Type A Failures

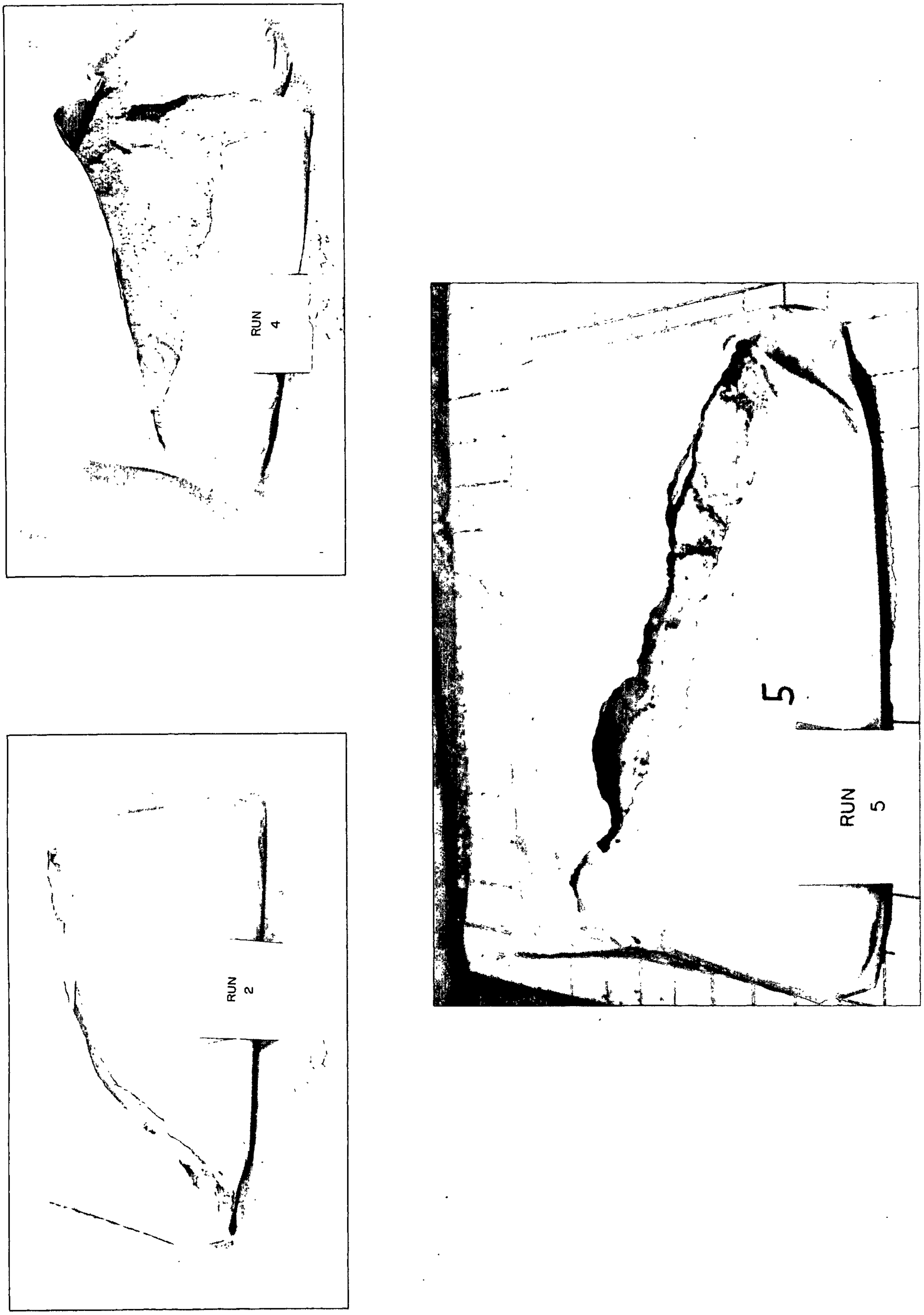

Figure 4. Type B Failures

Code

BF -- on face panel

BB -- on back panel

Type C. Corner Failure

For this failure class, the line of failure characteristically curves around the corner of the sack. One end of the failure line may a) extend as far as the side crease (see Fig. 5) or b) form a crescent shape with the end of the tear in the face or back pointing back toward the end of the sack. The other end of the failure line usually reaches the top or bottom of the sack near midwidth. In analyzing the data two subdivisions were made.

Code

CF -- on face panel

CB -- on back panel

The failure class includes a variety of patterns as is apparent from the photographs. In general, it is felt that subdivision of this class might be desirable.

Type D. End-machine Direction

This class pattern characteristically forms a relatively short rupture near midwidth at top or bottom approximately parallel to the machine direction. Only a minor curvature toward the side of the sack is permissible. Two subdivisions were made as shown below and two photographs are shown in Fig. 6.

DF -- on face panel

DB -- on back panel

Figure 5. Class C Failures

Figure 6. Class D (Right) and Class E (Left) Failure Patterns

Type E. Diagonal Side Failure

The failure pattern for this class characteristically takes the form of a diagonal failure line on the side of the sack, generally near the quarter point along the sack length, and often curving on to the face or back of the sack near a corner. Two photographs are shown in Fig. 6.

Type F. Crease Failure

Failure patterns of this type are defined as a rupture along a crease with no significant deviations from the crease (see Fig. 7). In analyzing the sketches, four subdivisions were recognized as follows:

Code

FS -- side crease

FXF -- cross-direction crease at top or bottom on face

FXB -- cross-direction crease at top or bottom on back

FD -- diagonal crease.

In practice a number of the FX type failure occurred at the side of the sack running from face to back. The face or back identification is not suitable for such cases, and it is felt that the face or back notation should be omitted in future work.

Type G. Cross Direction

This failure pattern is defined as a predominantly cross-direction failure line not clearly associated with a fold or crease. Three subdivisions were recognized as follows:

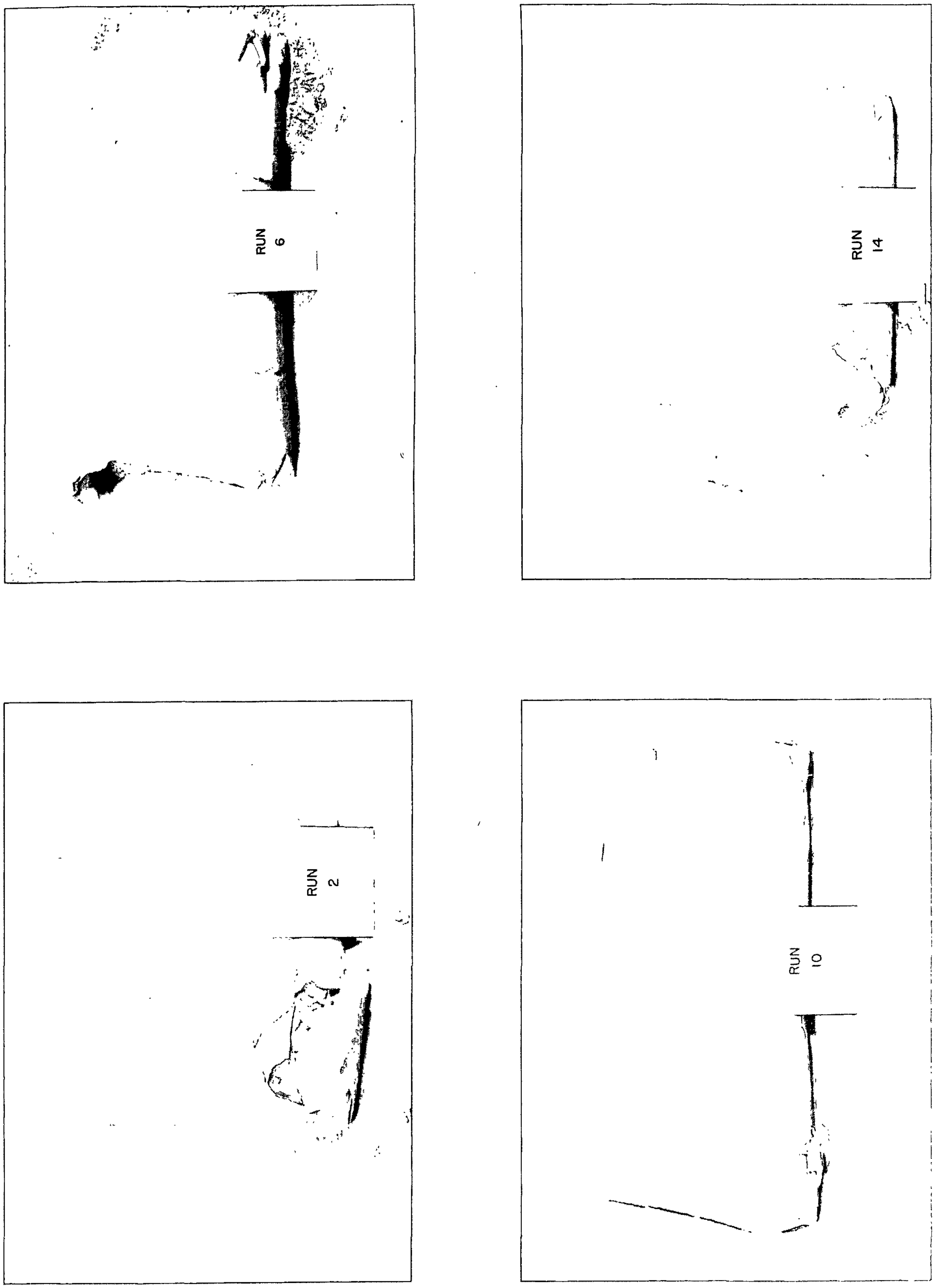

Figure 7. Type F Crease (Left) and Type H Valve or Corner Failures (Right)

Code

GE -- on top of bottom of sack

GF -- on face of sack

GB -- on back of sack

Type H. Valve Failure

This type failure is defined as a failure at the valve or in the vicinity of any corner--the failure pattern not resembling any of the other types (see Fig. 7).

DISCUSSION OF RESULTS

FAILURE PATTERN FREQUENCIES FOR REGULAR AND EXTENSIBLE SACKS

The distributions of failure patterns for sacks fabricated from regular sack paper are summarized in Table I. Referring to the table it may be noted that

1. "C" or failures around the corner of the sack were the most frequent type of failure pattern--accounting for 32% of the total number of failures.
2. A, B, E, and G type failures were about equally frequent--each accounting for 13 to 14% of the total number of failures.
3. Only a minor number of failure patterns fell in the remaining failure types, i.e., D, FS, FX, FD, and H. The five categories taken together accounted for only 11% of the total number of sacks involved. The importance of crease performance should not be minimized on this basis alone; however, as in certain other categories such as C, E, or G the failure line may cross or even follow a crease for a distance. Whether such failures originated at the crease and deviated therefrom or originated at some other location along the failure can only be conjectured at this time.
4. Restricting attention to the failure types exhibiting the higher frequencies such as A, B, C, E, and G, it may be noted that apparently significant differences in failure pattern frequency exist between runs. For example, A type failures ranged from 7 for Run DD to 1 for Run KK and C type failures ranged from 15 for Run AA to 6 for Runs HH and JJ. The relationship of such differences to the properties of the sack paper is discussed in later pages.

TABLE I

FAILURE PATTERN DISTRIBUTION FOR REGULAR SACKS

Run	Progressive Height Face Drop, safe inches	Number of Sacks per Failure Type									
		A	B	C	D	E	FS	FX	FD	G	H
AA	401	6	4	15	1	3	0	0	0	1	0
BB	370	1	2	8	2	8	2	1	0	5	1
CC	435	6	3	9	3	1	2	2	0	4	0
DD	288	7	4	12	0	2	0	1	0	3	1
EE	201	5	7	10	1	4	0	0	0	3	0
FF	222	4	7	11	2	0	3	1	0	2	0
GG	316	1	4	11	1	4	0	2	0	7	0
HH	296	5	3	6	0	6	2	1	0	6	1
II	338	5	8	10	1	1	0	1	0	4	0
JJ	487	6	3	6	1	6	0	0	1	6	1
KK	262	1	0	8	4	6	0	5	1	4	1
LL	281	1	4	11	2	7	0	1	0	4	0
Total		48	49	117	18	48	9	15	2	49	5
% of grand total		13	14	32	5	13	2	4	1	14	1
Av.		4	4	10	2	4	1	1	0	4	0

The results of similar analyses of the failure patterns exhibited by the sacks fabricated from extensible papers are summarized in Table II. In the table it may be noted that "A" or lengthwise failure patterns were predominant as about 55% of the sacks failed in this manner. Corner (C) type failures were next most frequent (13%), followed by B, D, and G type failures near 7 to 8%.

TABLE II

FAILURE PATTERN DISTRIBUTION FOR EXTENSIBLE SACKS

	Number of Sacks per Failure Type									
Run	A	B	C	D	E	FS	FX	FD	G	H
MM	6	2	9	5	2	1	1	0	2	2
NN	11	4	5	1	2	1	1	0	4	1
OO	14	0	3	4	2	1	0	0	2	4
PP	16	5	4	1	0	0	0	0	3	1
QQ	14	6	4	3	0	0	0	0	2	1
RR	20	2	2	1	0	1	0	0	1	3
SS	15	1	4	2	1	3	0	0	4	0
TT	17	5	3	3	0	0	0	0	1	1
UU	21	0	3	1	0	4	0	0	1	0
VV 17	17	0	6	4	1	1	0	0	1	0
WW	21	2	1	0	2	0	0	0	2	2
XX 16	22	2	0	2	0	2	0	0	2	0
YY	21	3	2	1	0	0	0	0	2	1
ZZ	14	3	8	0	0	0	0	0	4	1
Total	229	35	54	28	10	14	2	0	31	17
Grand total, %	55	8	13	7	2	3	0	0	7	4
Av.	16	3	4	2	1	1	0	0	2	1

To facilitate comparison of the regular and extensible sacks, the overall percentage frequencies are tabulated in Table III. As may be noted, striking differences in failure patterns existed. The major differences were:

1. The lengthwise A-type failures increased from 13% for the regular to 55% for the extensible sacks.

2. The corner C type failures decreased from 32% for the regular to 13% for the extensible sacks.

3. The extensible sacks exhibited lower percentage frequencies for the B, E, FX, and G type failure patterns. In this connection it is interesting to note that E-type failures were almost nonexistent for the extensible sacks and that no end crease (FX) failures were recorded for the extensible sacks.

TABLE III

COMPARISON OF REGULAR AND EXTENSIBLE SACK FAILURE PATTERNS

Type	Description	Frequency, % Regular	Frequency, % Extensible
A	Lengthwise	13	55
B	Diagonal or forked lengthwise	14	8
C	Corner	32	13
D	End-machine direction	5	7
E	Diagonal side	13	2
FS	Side crease	2	3
FX	End crease	4	0
FD	Diagonal crease	1	0
G	Cross direction	14	7
H	Valve or corner	1	4

RELATIONSHIP OF FAILURE PATTERN FREQUENCY TO SHEET PROPERTIES

As noted above, the most striking difference in failure pattern between regular and extensible sacks was the increase in A-type failures for the extensible sacks. This failure pattern characteristically assumed the form of a relatively straight failure line parallel to the machine direction in the face or back of the sack as shown in Fig. 3. The direction of this failure line is similar to that exhibited by a common cross-machine tensile test specimen. Therefore, it is tempting to conclude that this type of sack failure resulted when the applied strains in the cross direction of the sack walls exceeded the ultimate cross-machine stretch of the sack paper. This interpretation is qualitatively in agreement with the stretch or TEA characteristics of regular and extensible sack paper. The average values of these properties for the sack papers of this study are as follows:

	Stretch, %			TEA, in. lb./sq. in.		
	In	Cross	Ratio	In	Cross	Ratio
Regular	1.5	3.3	0.45	0.328	0.466	0.70
Extensible	9.2	4.6	2.0	1.245	0.576	2.16

Thus, where the cross-machine properties are lower than the machine-direction properties (extensible sacks), a greater proportion of cross-machine type failure patterns were observed. The converse held true for the regular papers where the cross-machine properties are generally higher than the machine-direction properties.

While the above discussion centered attention on the "A"-type failure patterns because of their a) frequent occurrence and b) resemblance to cross-machine tensile failures, a number of the other failure patterns may also be considered to <u>crudely</u> resemble cross-machine type failures. These failure pattern types are 1) B, 2) D, and 3) FS. As previously defined, D-type failures were short failure lines near midwidth at top or bottom approximately parallel to the machine direction and FS-type failures were side crease failures. The B-type failures were quite similar to A-type failures in that the failure line tended to be of the lengthwise type; however, the rupture either forked to the corners or pursued a diagonal path. The general machine-direction path of the above failure types suggested that as a first approximation they could also be considered to represent predominantly cross-machine direction failures.

With the above in mind, failures of the following types were summed together for each run in Tables IV and V for the regular and extensible sacks.

a) A plus B type failures.

b) A plus B plus D type failures.

c) A plus B plus D plus FS type failures.

The sum for each run is shown both as a total and as a percentage of the number of sacks tested per run. For example, in Table IV, 10 or 33% of the sacks tested for run AA exhibited A or B type failure patterns. Also shown in the tables are the average (for all three plies) stretch, TEA, tear, and Frag values for each run.

In Fig. 8 and 9 the number of occurrences or per cent of A + B type failures are plotted against the machine ($\underline{W}_x$) and cross-machine ($\underline{W}_y$) TEA values, respectively. Similar graphs for the sum of all four failures are shown in Fig. 10 and 11. Referring to the figures, it may be noted that no obvious relationship between the frequency of occurrence of cross-machine failure types and the properties in either direction exists. This is not unexpected as the frequency of cross-machine type failures should depend on the ratio of machine to cross-direction properties for a given sack size. For example, for a given sack size, if the machine to cross-direction ratio of stretch or TEA were large (as for many extensible papers), a high proportion of cross-machine type failures would be anticipated. Conversely, if the machine to cross-direction ratio were less than unity, a low proportion of cross-machine type failures should be obtained.

The above viewpoint is illustrated in Fig. 12 and 13 where the frequency of occurrence of cross-machine type failures (A + B + D and A + B + D + FS) are plotted against the ratio of machine to the sum of machine plus cross-machine TEA

TABLE IV

COMPARISON OF CROSS-MACHINE FAILURE TYPES WITH SHEET PROPERTIES
(Regular sack paper)

Run	A + B Failures No.	A + B Failures Per-cent[a]	A + B + D Failures No.	A + B + D Failures Per-cent[a]	A+B+D+FS Failures No.	A+B+D+FS Failures Per-cent[a]	Stretch, % In (e_x)	Stretch, % Cross (e_y)	Stretch, % $\frac{e_x}{e_x+e_y}$	TEA, in. lb./sq. in. In (W_x)	TEA, in. lb./sq. in. Cross (W_y)	TEA, in. lb./sq. in. $\frac{W_x}{W_x+W_y}$	Elmendorf Tear, g./sheet In (T_x)	Elmendorf Tear, g./sheet Cross (T_y)	Elmendorf Tear, g./sheet $\frac{T_x}{T_x+T_y}$	Frag, kg.m. x 10^{-4} In (F_x)	Frag, kg.m. x 10^{-4} Cross (F_y)	Frag, kg.m. x 10^{-4} $\frac{F_x}{F_x+F_y}$
AA	10	33	11	37	11	37	1.8	3.4	0.35	0.417	0.517	0.45	122	132	0.48	459	618	0.43
BB	3	10	5	17	7	23	1.6	3.5	0.32	0.358	0.467	0.43	134	135	0.50	337	445	0.43
CC	9	30	12	40	14	47	1.5	4.6	0.25	0.303	0.541	0.36	142	142	0.50	318	502	0.39
DD	11	37	11	37	11	37	1.4	2.9	0.32	0.354	0.385	0.48	110	126	0.47	503	424	0.54
EE	12	40	13	43	13	43	1.4	2.7	0.34	0.318	0.343	0.48	123	137	0.47	370	371	0.50
FF	11	37	13	43	16	53	1.4	2.8	0.33	0.261	0.321	0.45	139	136	0.50	275	328	0.46
GG	5	17	6	20	6	20	1.3	3.5	0.27	0.284	0.536	0.35	118	123	0.49	347	523	0.40
HH	8	27	8	27	10	33	1.4	2.8	0.33	0.282	0.414	0.41	130	136	0.49	303	438	0.41
II	13	43	14	47	14	47	1.7	2.9	0.37	0.363	0.431	0.46	113	128	0.47	405	484	0.46
JJ	9	30	10	33	10	33	1.7	3.9	0.31	0.412	0.573	0.42	117	124	0.48	606	664	0.48
KK	1	3	5	17	5	17	1.4	3.4	0.29	0.265	0.521	0.34	115	122	0.48	284	506	0.36
LL	5	17	7	23	7	23	1.5	3.5	0.30	0.324	0.544	0.37	109	121	0.47	340	503	0.40

[a]Based on 30 sacks tested per run.

TABLE V

COMPARISON OF CROSS-MACHINE FAILURE TYPES WITH SHEET PROPERTIES
(Extensible sack paper)

Run	A + B Failures No.	A + B Failures Per-cent[a]	A + B + D Failures No.	A + B + D Failures Per-cent[a]	A+B+D+FS Failures No.	A+B+D+FS Failures Per-cent[a]	Stretch, % In (e_x)	Stretch, % Cross (e_y)	Stretch, % $\frac{e_x}{e_x+e_y}$	TEA, in. lb./sq. in. In (W_x)	TEA, in. lb./sq. in. Cross (W_y)	TEA, in. lb./sq. in. $\frac{W_x}{W_x+W_y}$	Elmendorf Tear, g./sheet In (T_x)	Elmendorf Tear, g./sheet Cross (T_y)	Elmendorf Tear, g./sheet $\frac{T_x}{T_x+T_y}$	Frag, kg.m. x 10^{-4} In (F_x)	Frag, kg.m. x 10^{-4} Cross (F_y)	Frag, kg.m. x 10^{-4} $\frac{F_x}{F_x+F_y}$
MM	8	27	13	43	14	47	6.3	4.9	0.56	0.954	0.714	0.57	118	131	0.47	771	576	0.57
NN	15	50	16	53	17	57	8.7	4.4	0.66	1.181	0.639	0.65	121	131	0.48	801	444	0.64
OO	14	47	18	60	19	63	11.3	4.3	0.72	1.403	0.656	0.68	132	151	0.47	876	419	0.68
PP	21	70	22	73	22	73	6.5	4.7	0.58	1.021	0.542	0.65	118	152	0.44	676	546	0.55
QQ	20	67	23	77	23	77	9.0	4.9	0.65	1.311	0.573	0.70	130	152	0.46	725	525	0.57
RR	22	73	23	77	24	80	12.6	5.5	0.70	1.574	0.672	0.70	127	163	0.44	814	491	0.62
SS	16	53	18	60	21	70	6.2	4.2	0.60	0.970	0.462	0.68	113	148	0.43	527	418	0.56
TT	22	73	25	83	25	83	8.8	4.8	0.65	1.241	0.572	0.68	115	145	0.44	569	405	0.58
UU	21	70	22	73	26	87	11.7	4.8	0.71	1.511	0.570	0.73	126	162	0.44	608	386	0.61
VV	17	57	21	70	22	73	9.2	5.2	0.64	1.341	0.656	0.67	128	150	0.46	833	511	0.62
WW	23	77	23	77	23	77	8.8	4.5	0.66	1.039	0.474	0.69	122	147	0.45	521	320	0.62
XX	24	80	26	87	28	93	9.8	3.6	0.73	1.325	0.428	0.76	137	180	0.43	676	379	0.64
YY	24	80	25	83	25	83	8.9	4.9	0.65	1.203	0.553	0.69	128	161	0.44	677	468	0.59
ZZ	17	57	17	57	17	57	10.9	4.3	0.72	1.353	0.550	0.71	124	143	0.47	698	408	0.63

[a]Based on 30 sacks tested per run.

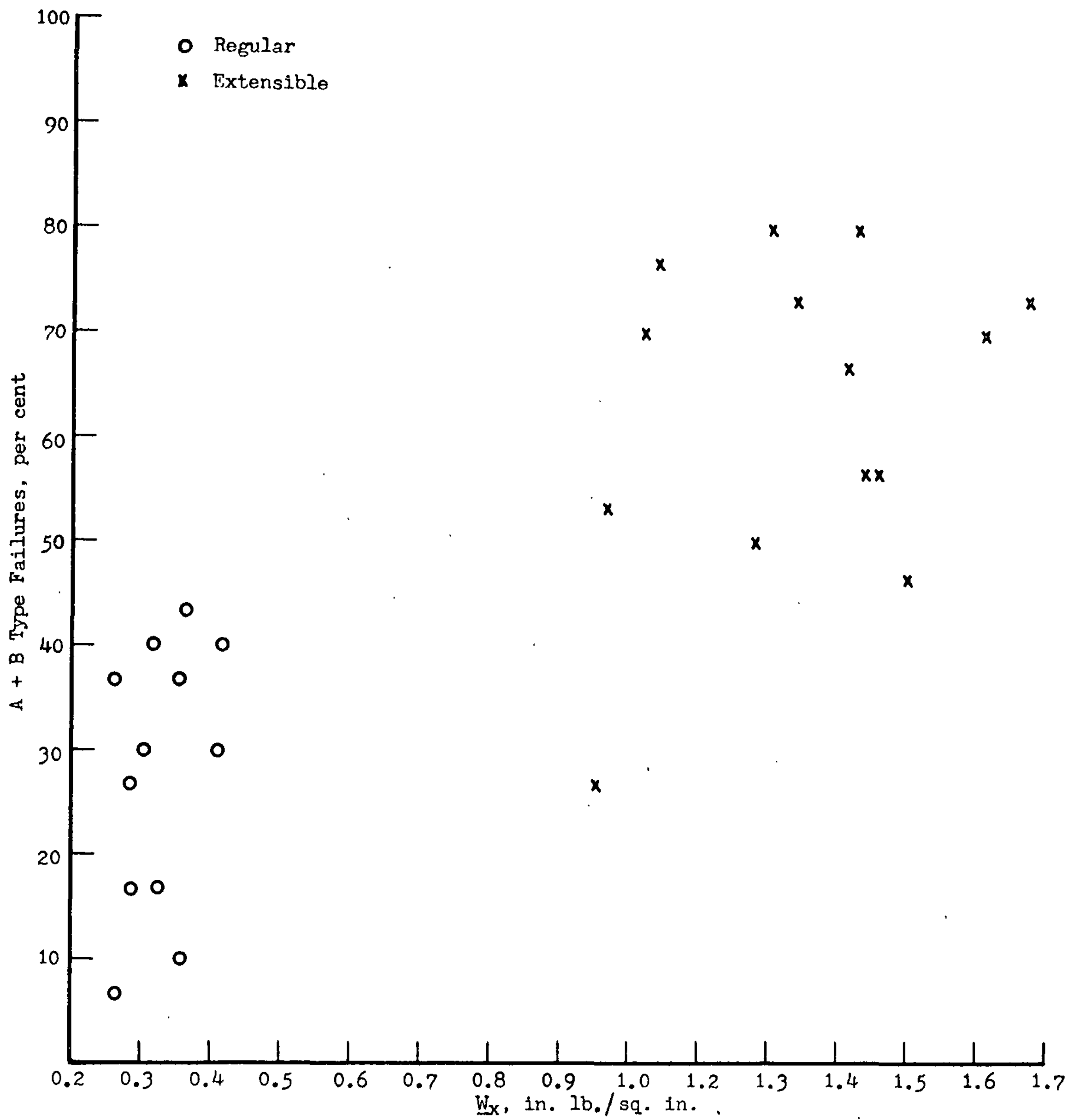

Figure 8. Relationship Between the Frequency of Occurrence of Cross-Machine Failure Types A and B and Machine Direction TEA ($\underline{W}_x$)

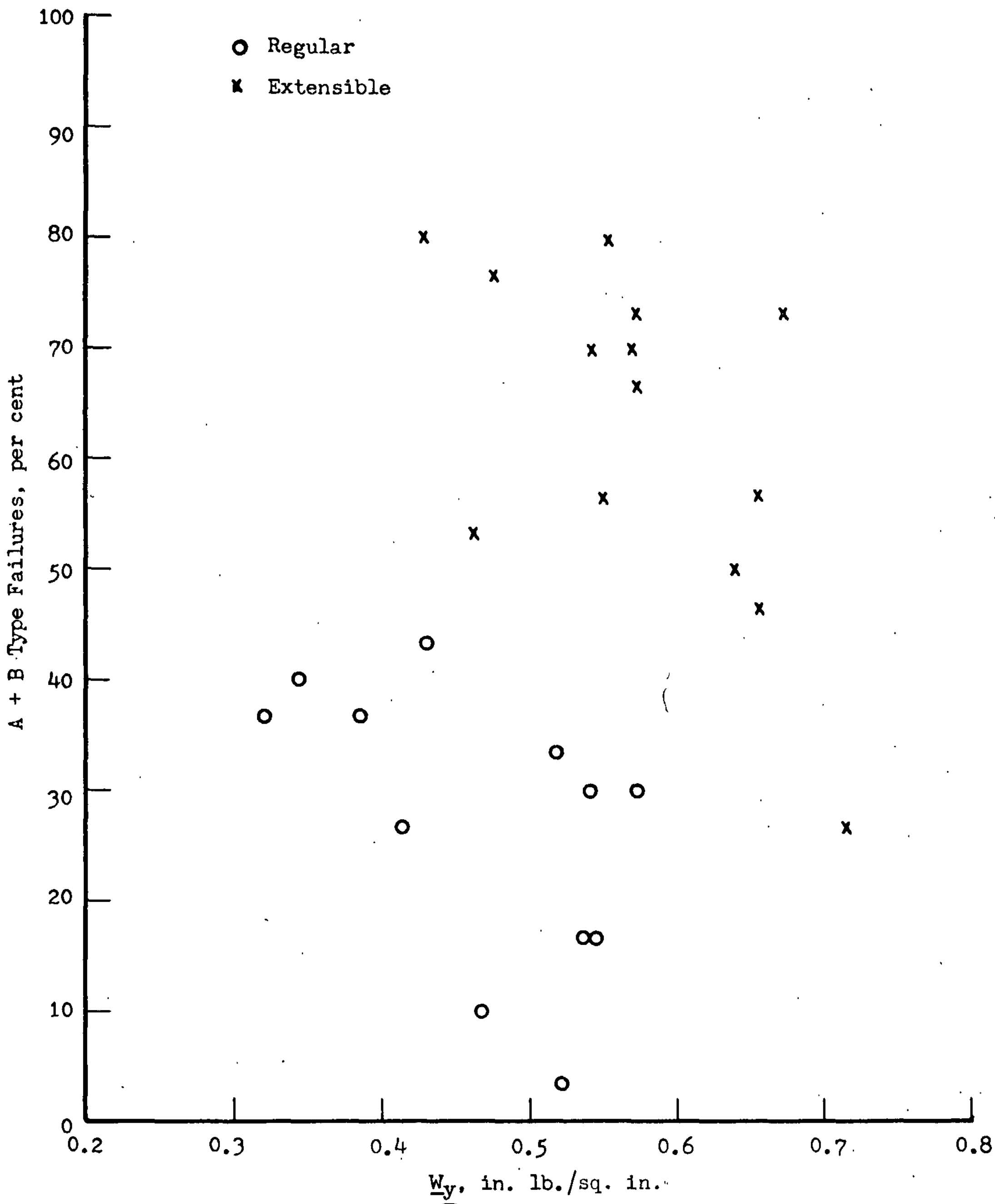

Figure 9. Relationship Between the Frequency of Occurrence of Cross-Machine Failure Types A and B and Cross-Machine Direction TEA (W_y)

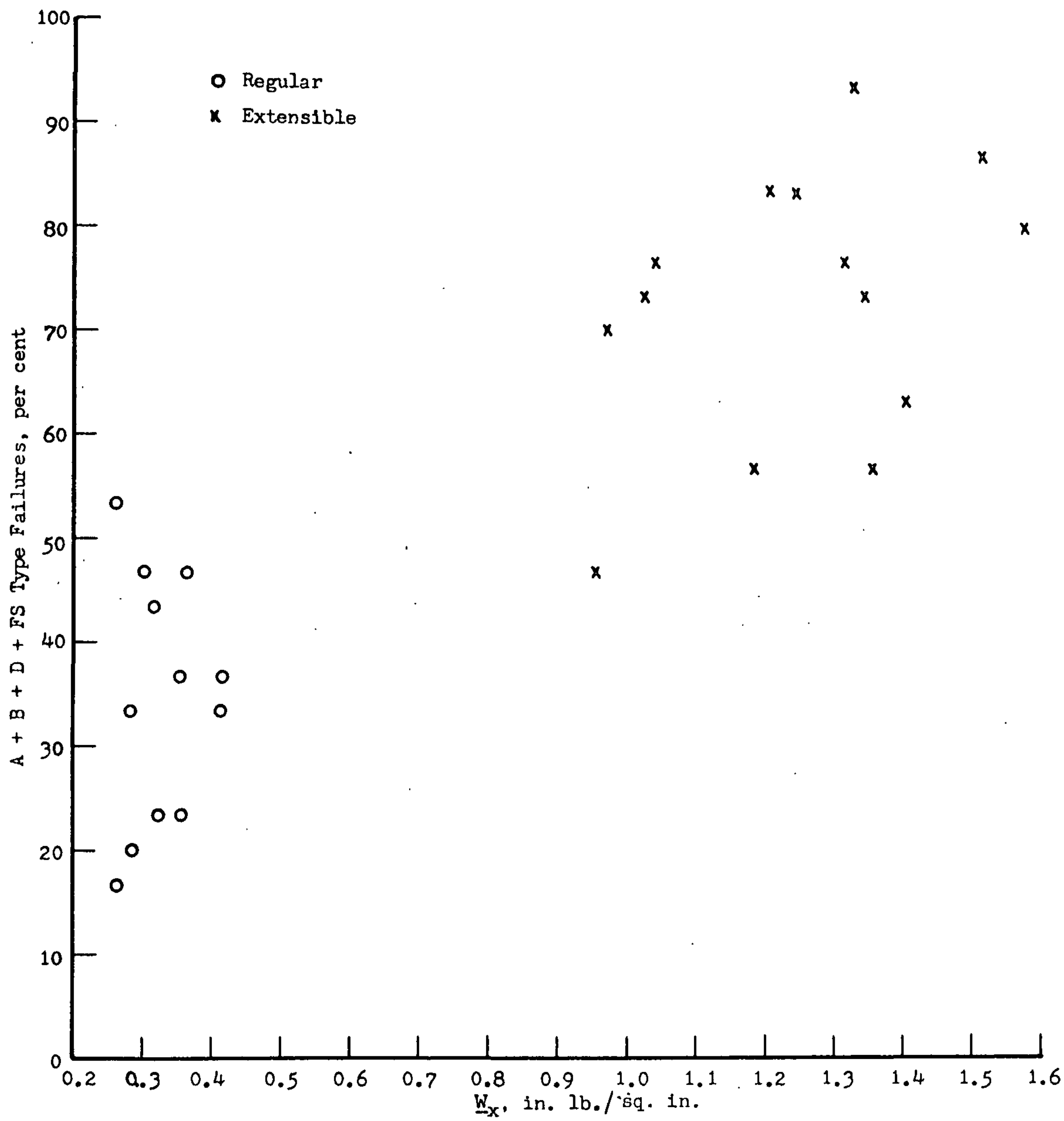

Figure 10. Relationship Between the Frequency of Occurrence of Cross-Machine Direction Failure Types A, B, D, and FS and Machine Direction TEA ($\underline{W}_x$)

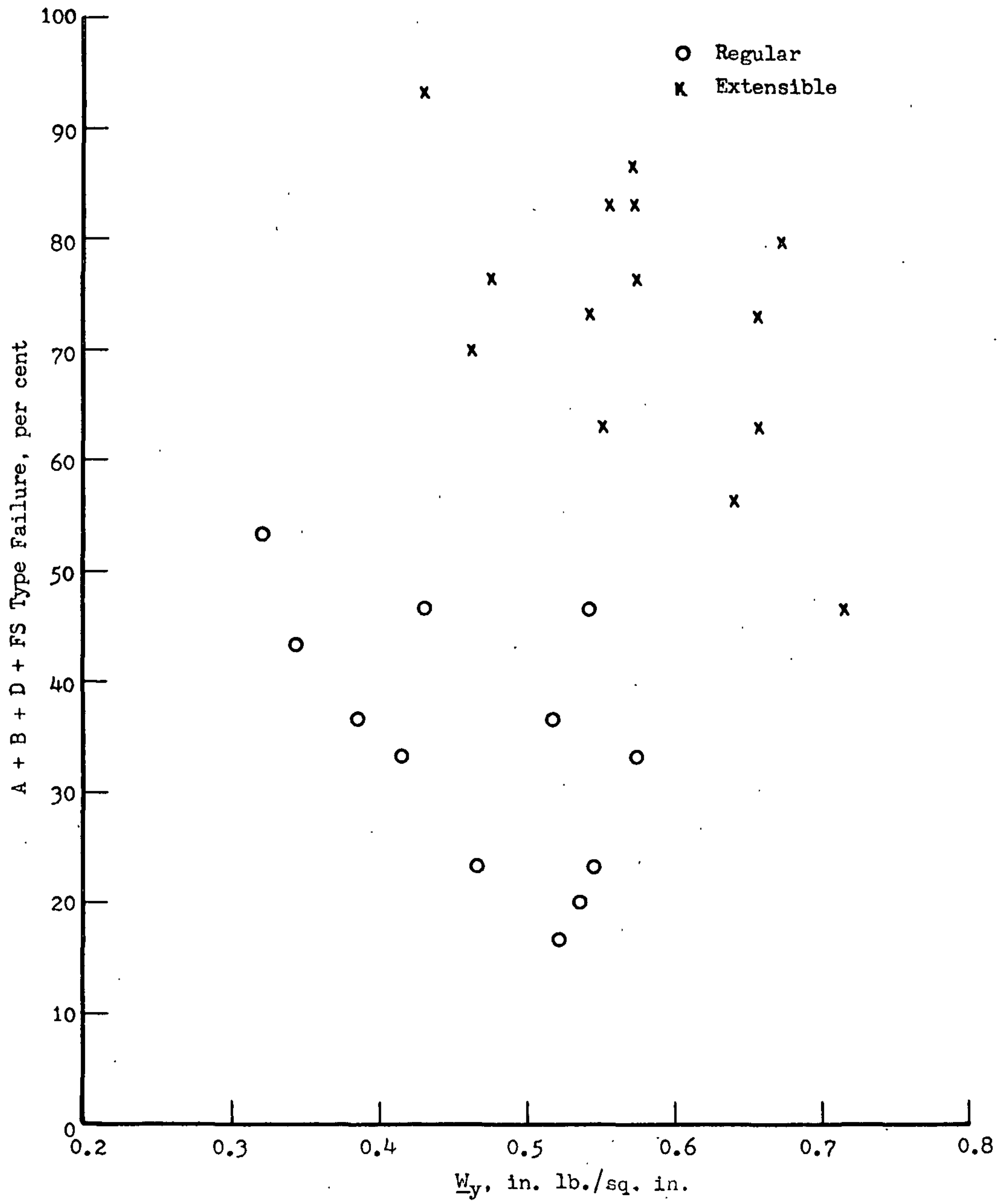

Figure 11. Relationship Between the Frequency of Occurrence of Cross-Machine Direction Failure Types A, B, D, and FS and Cross-Machine Direction TEA ($\underline{W}_y$)

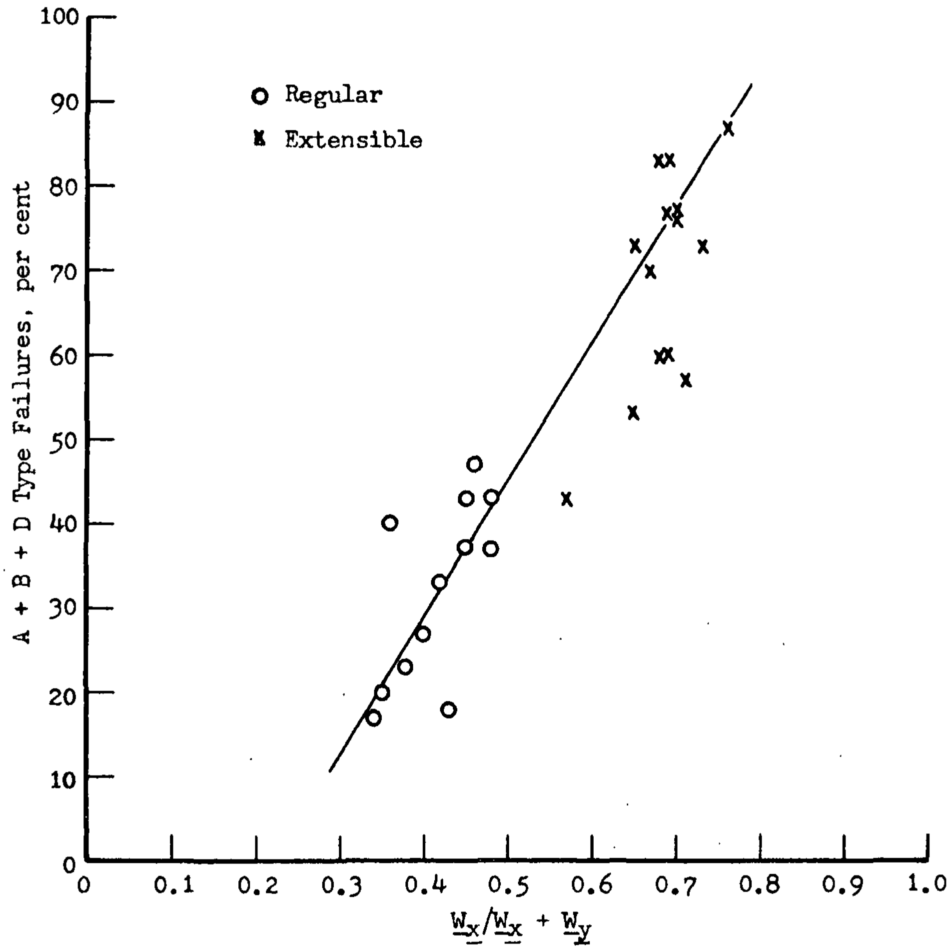

Figure 12. Relationship Between the Frequency of Cross-Machine Failure Types A, B, and D and the Ratio of Machine-to-Machine plus Cross-Machine TEA

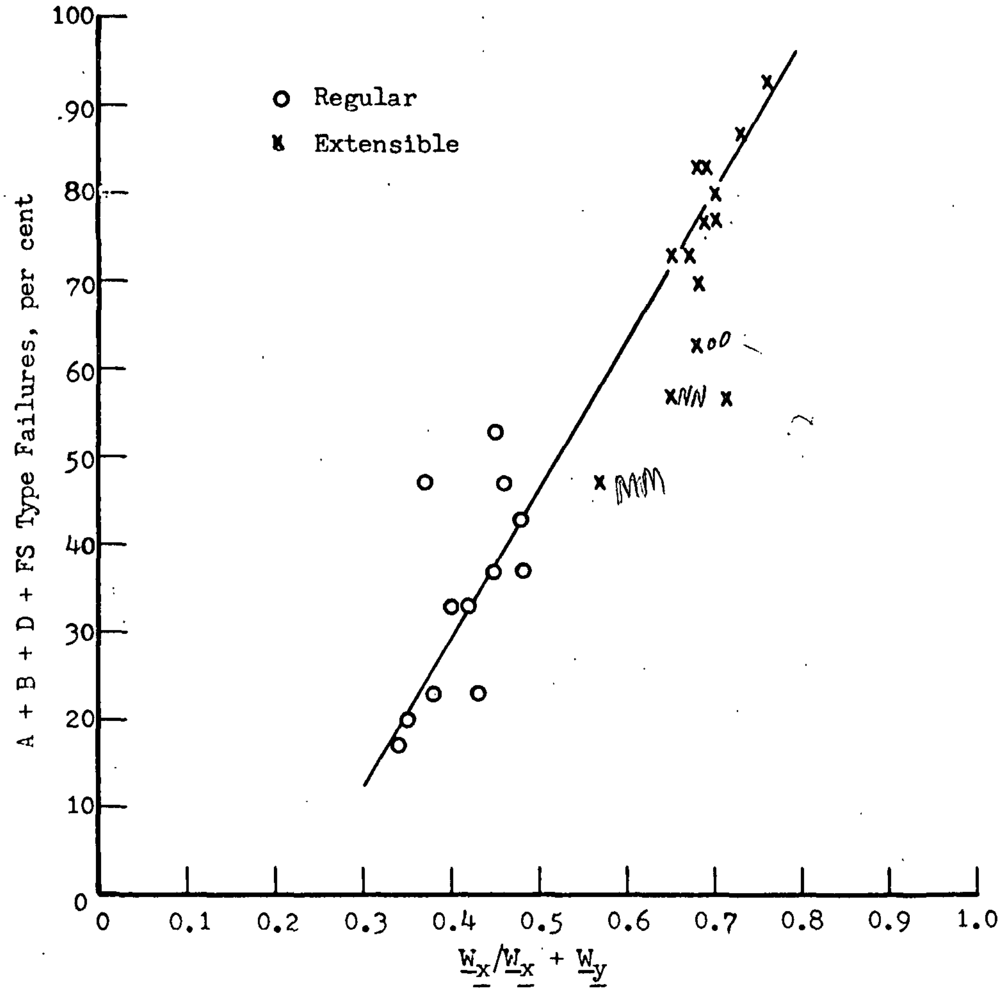

Figure 13. Relationship Between the Frequency of Cross-Machine Failure Types A, B, D, and FS and the Ratio of Machine-to-Machine plus Cross-Machine TEA

($\underline{W}_x/[\underline{W}_x + \underline{W}_y]$). Despite the considerable scatter in the data, both figures appear to support the hypothesis that the frequency of cross-machine failure patterns is dependent in part on the ratio of the sheet properties in the two directions. As one consequence, it reinforces the viewpoint that face drop sack performance should be treated as a biaxial strain or energy process, i.e., that face drop sack performance involves sheet properties in both principal directions and also dimensions.

The straight lines in Fig. 12 and 13 were drawn in by "eye." It may be remarked that a graph of the data of Fig. 13 in logarithmic co-ordinates (see Fig. 13A) yields a reasonable straight line with slope near 2. This indicates that cross-machine failure frequency is a nonlinear function of $\underline{W}_x/[\underline{W}_x + \underline{W}_y]$ and suggests that the straight line in Fig. 13 should be replaced with a curve.

It may also be remarked that graphs of cross-machine failure frequency versus $\underline{W}_x/\underline{W}_y$ or $\underline{W}_y/\underline{W}_x$ were also prepared during the analysis of the data. Such graphs were not markedly dissimilar to those obtained with the function $\underline{W}_x/\underline{W}_x + \underline{W}_y$; however, it was felt that the latter function yielded more favorable plots. In this connection, it appears more logical to relate the fraction (percentage) cross-machine failure frequency to a fraction involving material properties such as $\underline{W}_x/\underline{W}_x + \underline{W}_y$ than to a simple ratio such as $\underline{W}_x/\underline{W}_y$. If one were plotting the ratio of cross-machine to machine failure frequency, then it might be more logical to select the simple ratio $\underline{W}_y/\underline{W}_x$ as the independent variable. Finally, since $\underline{W}_x/\underline{W}_x + \underline{W}_y = 1 - [\underline{W}_y/(\underline{W}_x + \underline{W}_y)]$, it should make little difference whether one chooses the ratio $\underline{W}_x/(\underline{W}_x + \underline{W}_y)$ or $\underline{W}_y/(\underline{W}_x + \underline{W}_y)$ as the independent variable. The main difference should be that slopes of opposite sign should be obtained.

The above discussion centered attention on failure types which could be <u>crudely</u> classified as cross-machine type. If this reasoning were approximately correct, then certain of the remaining types of failure patterns may be regarded

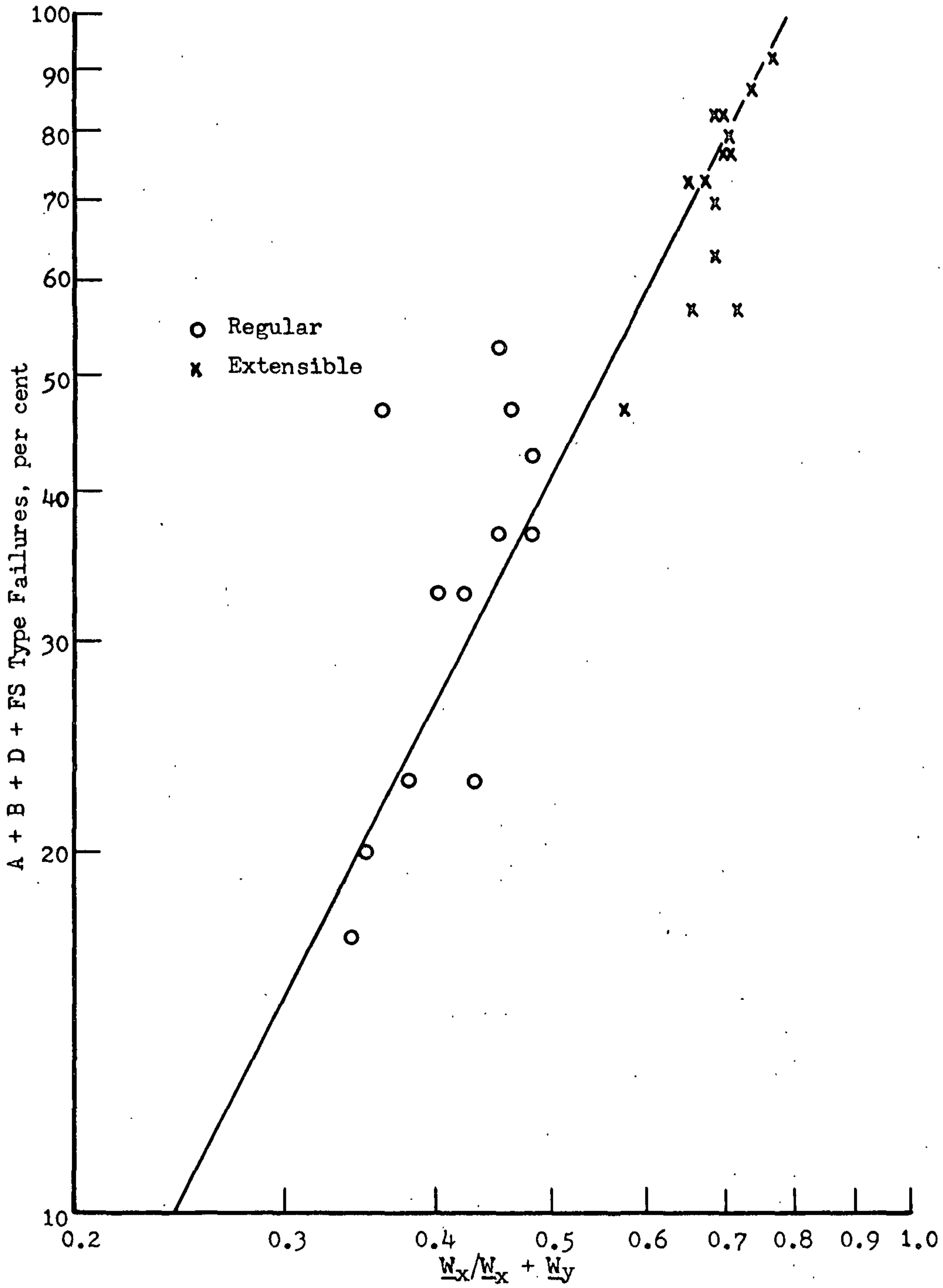

Figure 13A. Relationship Between Cross-Machine Failure Type Frequency and the Ratio of Machine to the Sum of Machine plus Cross-Machine TEA (Logarithmic Co-ordinates) as machine-direction types. The G and top crease failures (FX) appear to fall in this category. The E-type failures may occur as a result of the diagonal or vertical folds induced in the sack walls as the sack is lifted onto the drop table. Regarded in this light their assignment to the machine-direction failure class is, perhaps, logical. The C-type failure patterns are not obviously related to either direction which may be indicative that the class requires further subdivision and/or redefinition. In any event, these four classes make up the bulk of the failure patterns after subtraction of the cross-machine types (A, B, D, and FS). Therefore, it would be anticipated that a graph of the C, E, G, and FX failure types versus $\underline{W}_x/\underline{W}_x + \underline{W}_y$ (see Fig. 14) would result in a curve having a negative slope.

At this point, it may be argued that after initiation of failure, the subsequent course of the tear would be governed by the relative Elmendorf type tear resistance of the sheet. To investigate this possibility the cross-machine failure type (A + B + D + FS) frequency was plotted against the ratio of in-machine Elmendorf tear ($\underline{T}_x$) to the sum of machine and cross-machine ($\underline{T}_y$) Elmendorf tear. The graph is shown in Fig. 15 and it is clear that no relationship exists. This result is not unexpected because

1. Past efforts to relate Elmendorf tear to sack drop test performance have not been successful.
2. The appearance of the torn edge in a sack is usually quite different from that obtained in the tear test.
3. High-speed photography of sack failures gives no indication that the sheet is stressed in the manner employed in the Elmendorf continued tearing strength tester.

As discussed previously, a reasonable relationship between cross-machine failure type frequency and the tensile energy absorption of the sheet in both

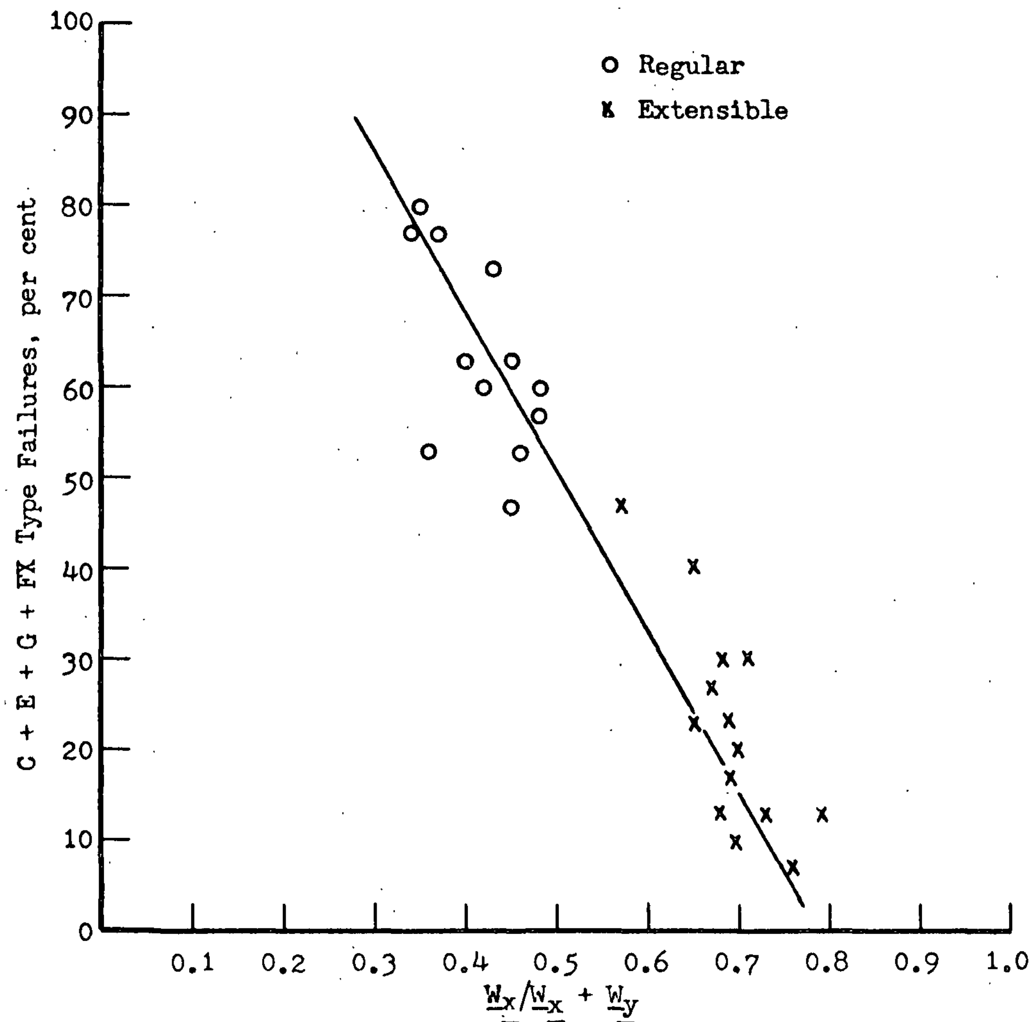

Figure 14. Relationship Between Failure Types C, E, G, and FX and the Ratio of Machine-to-Machine plus Cross Machine TEA

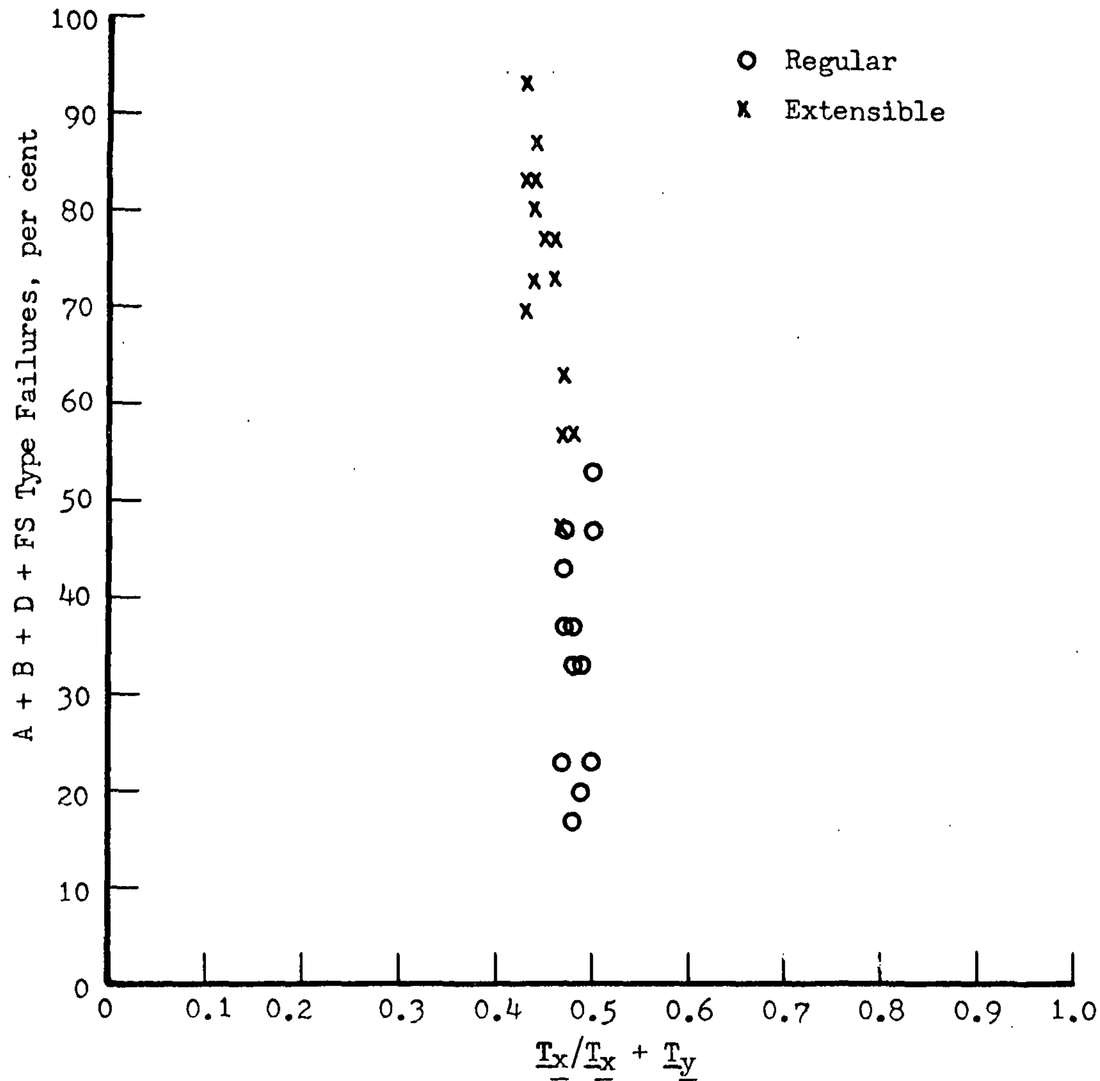

Figure 15. Relationship Between the Frequency of Cross-Machine Failure Types A, B, D, and FS and the Ratio of Machine to the Sum of Machine and Cross-Machine Elmendorf Tear

directions exists. It would be anticipated that other sheet properties which are related to TEA would also exhibit some relationship to failure type frequency. To illustrate this, graphs of cross-machine failure frequency were prepared using stretch and the Frag test results. In Fig. 16 the arrangement of points suggests that separate relationships for the regular and extensible sacks are required for stretch. The Frag relationship in Fig. 17 is somewhat similar to that obtained using TEA.

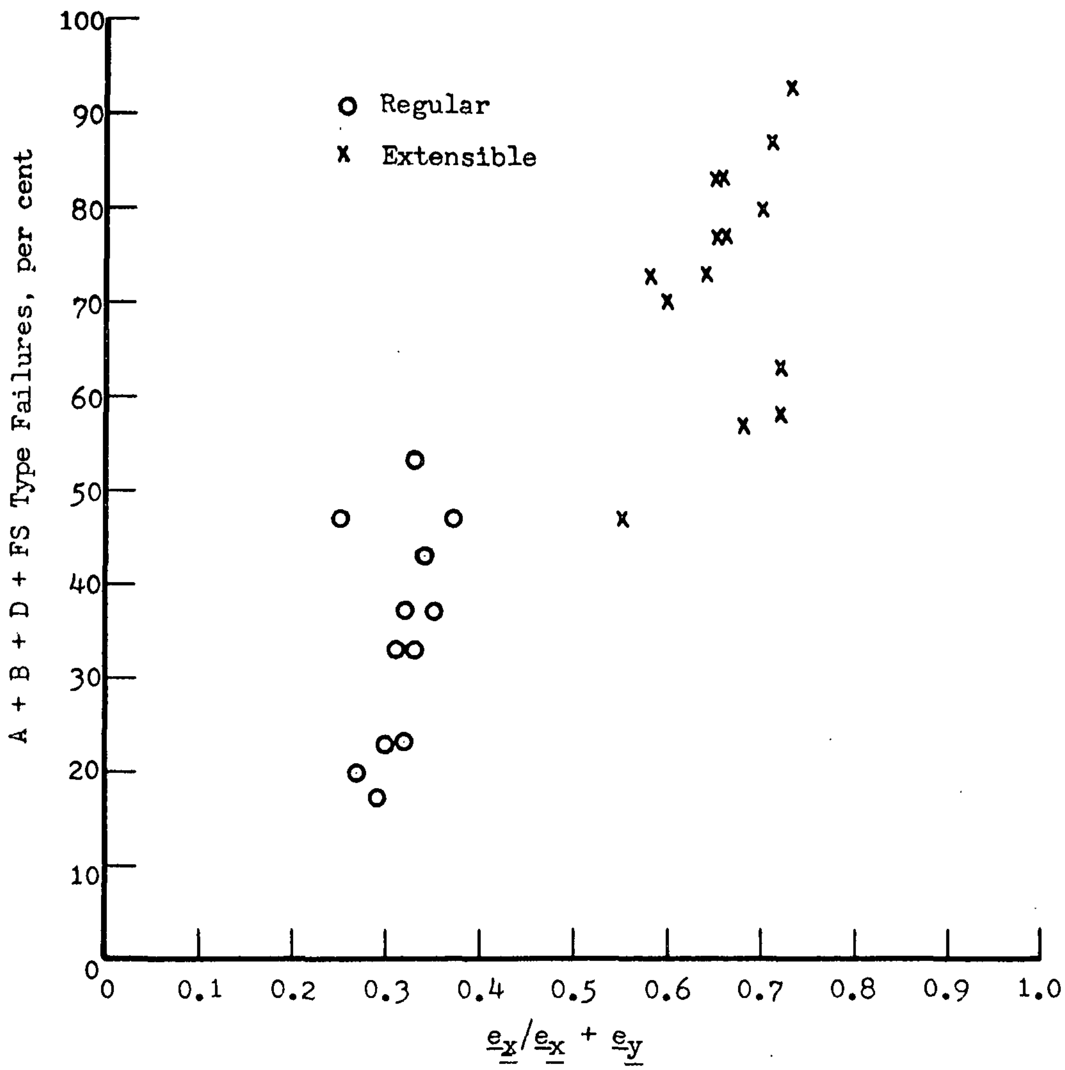

Figure 16. Relationship Between the Frequency of Cross-Machine Failure Types and the Ratio of Machine to the Sum of Machine and Cross-Machine Stretch

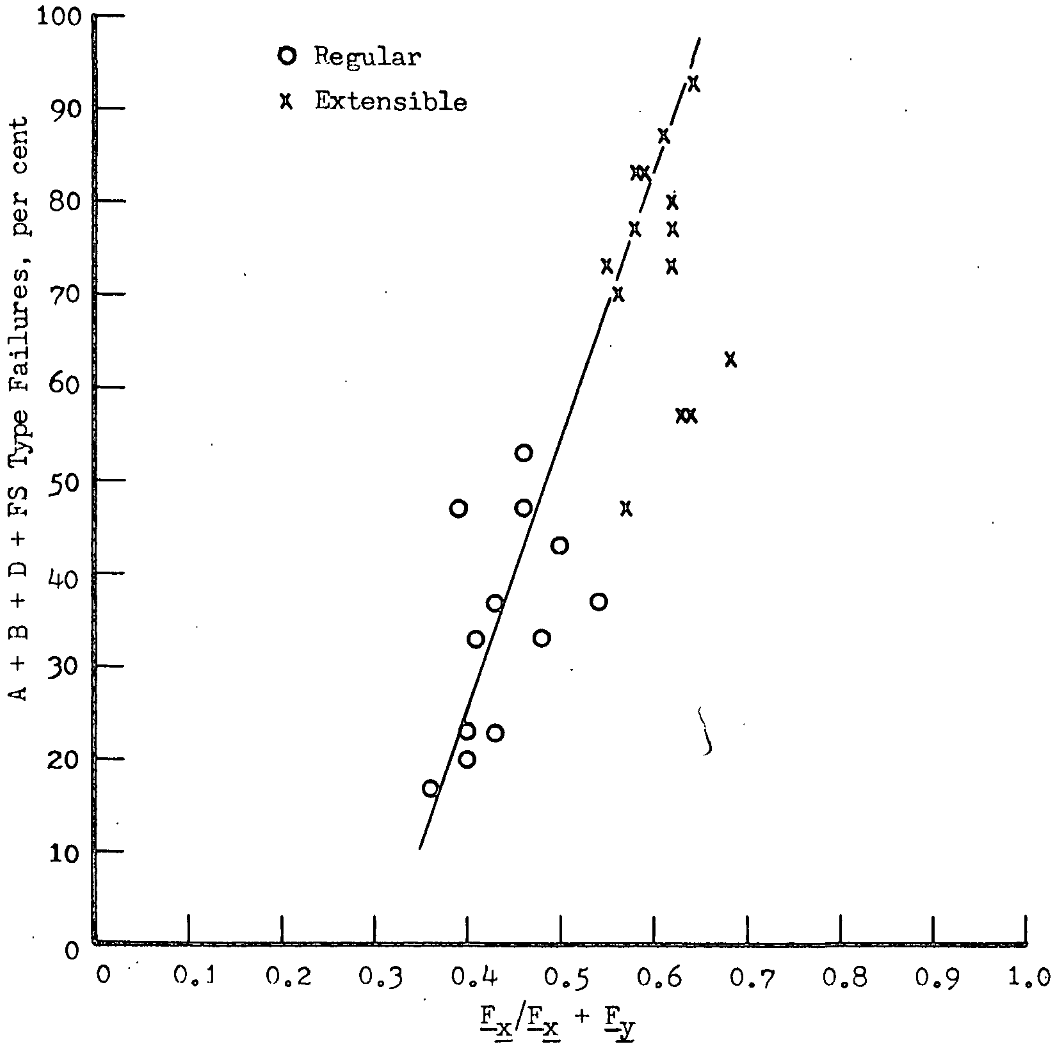

Figure 17. Relationship Between the Frequency of Cross-Machine Failure Types and the Ratio of Machine to the Sum of Machine and Cross-Machine Frag

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